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GRAPHIC METHOD

FOR SOLVING CERTAIN

ALGEBRAIC PROBLEMS

BY

GEORGE L. VOSE,

PROFESSOR OF CIVIL ENGINEERING IN BOWDOIN COLLEGE,
AUTHOR OF "MANUAL FOR RAILROAD ENGINEERS."

NEW YORK:
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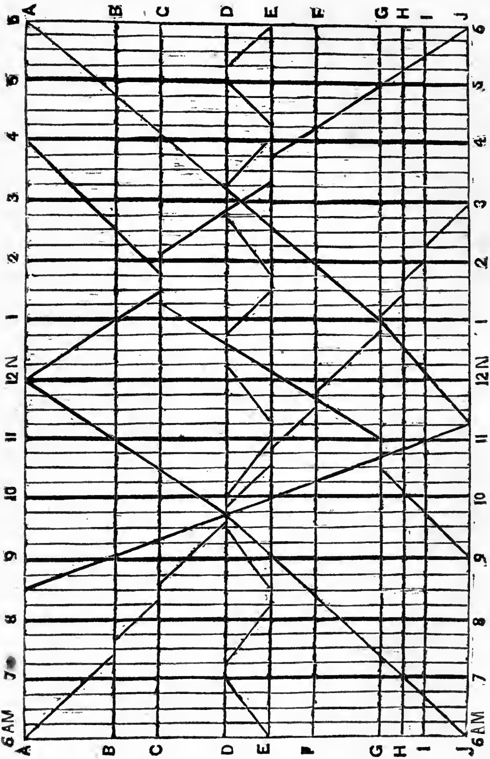

FIGURE 29, p. 57.

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PREFACE.

A portion of the following pages first appeared in VAN NOSTRAND'S ENGINEERING MAGAZINE for June, 1875. The method was suggested by the common mode of representing the movement of railway trains, which was employed as long ago as 1850, and was first brought to the writer's knowledge by the late S. S. Post, the well known Civil Engineer. It is, of course, not presented as in any way taking the place of the far more elegant and precise methods of analysis, but only as in some cases a convenient mode of obtaining a bird's-eye view of a problem, and as affording the means for interpreting certain results,

which by other processes are not at first sight quite plain.

The "Cross Section Paper," employed by engineers, will be found well adapted for the working of problems by the graphic method, as it is ruled in squares of greater or less size.

A GRAPHIC METHOD

FOR SOLVING

CERTAIN ALGEBRAIC PROBLEMS

The various methods ordinarily employed for the solution of mathematical problems are well known to all who are familiar with arithmetic, algebra and geometry. There is however a method of answering a certain class of questions, and of representing certain results, by a direct appeal to the eye, which is extremely simple, very effective and in some cases superior to every other mode. This process is, at least in some of its applications, by no means new to engineers, but it may be both new and interesting to some persons, and it is proposed therefore without further remarks

to present a few examples of the graphic method, the application of which to additional questions will readily be made by the reader.

Suppose we have the following question: If a man travels five miles in one hour, how far will he go in four hours. This of course is the plainest possible question in simple multiplication. But suppose instead of the above we have the problem below. A person walked a certain distance from A to B at the rate of three and a half miles an hour, and then ran a part of the way back from B to A, at the rate of seven miles an hour, walking the remaining distance in five minutes, and being out twenty-five minutes in all. A second man walks from B to A and back again, at a uniform rate, being also out twenty-five minutes in all. At what two times will he meet the first man, and how far from A will the two points of meeting be? Here now is a question which our simple multiplication will not answer; but by the graphic method the second question is nearly if not quite as simple as the first.

To begin with our first question above, draw a horizontal line and divide it into equal parts as at 1, 2, 3, in Fig. 1.

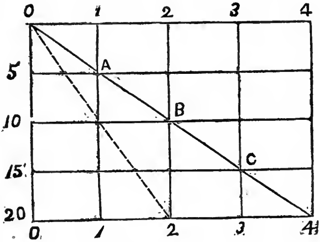

FIG. 1.

Let these equal horizontal distances represent hours. Through each of the points 0, 1, 2, 3 and 4 draw the vertical lines 0–0, 1–1, 2–2, 3–3 and 4–4, and upon the first vertical line lay off equal divisions as at 5, 10, 15 and 20, to represent miles, and through the points draw lines parallel to the upper horizontal. We have here *time* laid off upon one line, and *distance* laid off upon another line at right angles to the first. Now if the man travels five miles in one hour, his path is represented upon our diagram

by the diagonal line from 0 to A; any inclined line in the figure representing a movement both in space and time. If we wish to know how far the man will go in two hours we have only to draw a vertical through 2 to cut the diagonal at B, and from B to draw a horizontal line to our vertical scale of miles at 10; or if we wish to know how long the man will be in going fifteen miles we draw a horizontal from 15 to cut the diagonal at C, and through C draw a vertical to cut the time line at 3. If a second man goes twice as fast as the first, his path will be shown by the more steeply inclined line from 0, on the upper horizontal, to 2 upon the lower one, which passes through the intersection of one hour and ten miles. Suppose the question was as follows: Two men start from the same point at the same time one going at the rate of five miles and the other at ten miles an hour; how far apart will they be at the end of two hours? We see at once that the vertical distance between our two inclined lines, measured upon

the perpendicular through 2, is the difference between ten and twenty miles, or ten miles. Let us reverse the question, thus: Two men start from the same point at the same time, and travel, one at the rate of five and the other at the rate of ten miles an hour; after a certain time they are ten miles apart; how long have they been traveling? Here we have only to take our distance representing ten miles and find where it will just go in vertically between the inclined lines, and then produce it upwards till it cuts the time line, which in this case is at 2; thus showing that they have been traveling two hours. Suppose again that our first man starts from a certain point, and that at the end of four hours he has gone twenty miles. A second man starts from the same point at the same time and reaches the end of the twenty miles two hours sooner than the first man; how fast did he travel? In this case we have only to go back upon the horizontal line from 4 to 2, and draw a

line from 2 upon the lower horizontal to 0 upon the upper one; the inclination of this line will give us the rate required, or ten miles an hour.

The above questions are extremely simple, so simple indeed as to be done in the head by any member of a common school, but they illustrate the method, which we will apply directly to more difficult problems.

We have seen that differently inclined lines represent different rates of movement. Let us take another question: X starts from a certain point and travels in a certain direction for a certain time, his path being represented by the diagonal A B in Fig. 2.

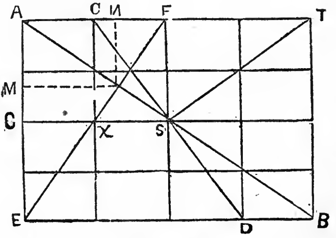

FIG. 2.

Y starts an hour later and passing over the same distance arrives an hour earlier. How fast did Y go, and when and where did he pass X? The line C D in the diagram represents the movement of Y, its inclination shows his rate, and he passes X at a distance represented on the vertical scale by F S, and at the time shown by F upon the upper horizontal. A third man, Z, starts from the opposite end of the course at the same time that X leaves the first end, and goes at the rate of the second man, Y; when and where will he cross the paths of the two other men? It will be seen that while two men may move in opposite directions *time* always goes in the same direction, and though a man may stand still, or even retrace his steps, *time* always goes on. As a matter or convenience time is always represented as going from left to right, in a horizontal direction. The movement of the third man Z is therefore shown by the line E F and he will pass X at M on the scale of miles, and at the time represented by N. He

will also pass Y on the second horizontal for distance, and half way between C and F for time. Let us change the question with regard to Z, thus: Z leaves the second end of the route at the same time that X leaves the first end, but travels twice as fast until he has gone half the length of the course, when he stops until Y overtakes X and then goes on arriving at X's starting point at the same time that X arrives at his (Y's) starting point. What is Z's rate during the last half of his course? In this case the first half of Z's course is represented by the line E X; but as he now stops for an hour we pass along *on the horizontal* from X to S. The remainder of his course is shown by the diagonal from S to T, the inclination of which is evidently the same as that of S B. The rate of Z therefore during the last half of his course is the same as the uniform rate of X.

The various algebras and arithmetics abound in questions like the following: Edinburgh is 360 miles from London.

A starts from Edinburgh and travels at the rate of 10 miles an hour; B starts from London and goes eight miles an hour. If they travel towards each other when and where will they meet? In this case we lay off E L, Fig. 3,

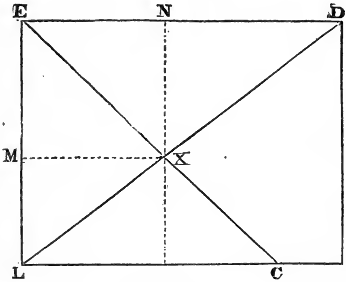

Fig. 3.

equal by any scale to 360 miles. Next laying off any equal parts upon the line E D, to represent hours, we draw the diagonal E C at such an inclination as to show the rate of A, viz. ten miles an hour. As B goes in the opposite direcion the diagonal showing his movement will be inclined as by the line L D, the angle of which is of course to represent

the speed of eight miles an hour. The diagonals cross at X, from which point we draw X M and X N. E M by our vertical scale of miles will be the distance from Edinburgh, and N upon the time line will show the time at which the two men meet.

Let us try the following question. A privateer running at the rate of ten miles an hour sees a ship eighteen miles off going at the rate of eight miles an hour; how far can the ship go before it is overtaken. Let A B, Fig. 4,

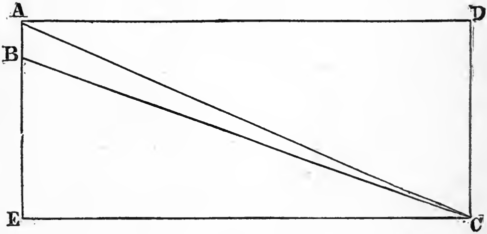

Fig. 4.

represent the eighteen miles which the ship is in advance of the privateer when first seen. Also let A C represent the

privateer's rate, or ten miles an hour, and let B C represent the rate of the ship, or eight miles an hour. The diagonals produced will intersect at C, and drawing C D and C E we have A D for the time and B E as the distance which the ship can go before being overtaken.

Suppose that we have the following question: Two towns are fifty miles apart, A is to leave one of these towns at six o'clock and to arrive at the other at noon, making four stops of half an hour each at ten, twenty, thirty, and forty miles from the starting point. B leaves the other end of the road at seven o'clock, travels twenty miles an hour for one hour, then turns back and retraces his course for an hour at the rate of ten miles an hour, then turns around and advances again at such a rate as to meet A as he is starting from his third halt ; continuing at the same rate B meets at half past ten a third man, C, who left the first end of the route two hours later than A did and has been going at a uni-

form rate. At what rate has C been traveling, and where did B meet him? By the ordinary process this question would not be a simple one, but it is quite so by the graphic method, as seen by the diagram, Fig. 5, in which

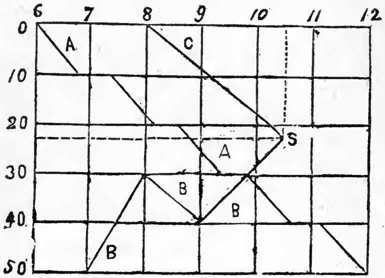

Fig. 5.

B is seen to meet C at about 23 miles from A's starting point, and C is found to have been going at the rate of about nine and a half miles an hour. Our figure is too small to give the required result with accuracy. It is to be observed in regard to all of these problems that the size and the proportion

of the diagram must depend entirely upon the degree of accuracy which it is desired to obtain, and also upon the character of the question. Very oblique cuttings of diagonals should be avoided.

Todhunter gives the following in his elementary algebra. A person walked out a certain distance from A to B at the rate of three and a half miles an hour, and then ran part of the way back again at the rate of seven miles an hour, walking the remaining distance in five minutes. He was out 25 minutes ; how far did he run? Let A B, Fig. 6, repre-

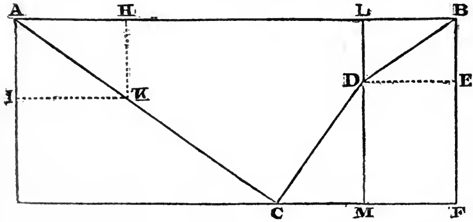

Fig. 6.

sent the whole time, or 25 minutes. Lay off A H equal to any convenient fraction of an hour, and A I equal to the

corresponding fraction of three and a half miles: the diagonal A K will then by its inclination represent the rate of three and a half miles an hour; produce this diagonal indefinitely toward C. Next lay off B L equal to five minutes upon the time scale, draw the vertical L M, and the diagonal B D inclined at the same rate as the line A K. Finally from D draw the diagonal D C inclined at such a rate as to represent seven miles an hour, upon the same scales of course as A C represents three and a half miles an hour, and produce it to intersect A C at C. The whole distance between the two points is then shown by B F, and the distance which the man ran by D M or E F, measured of course by the same scale of miles before employed.

Suppose to the preceding question we add the following: While the man above referred to walks from A to B, and runs and walks back again, a second man walks from B to A and back again from A to B, at a uniform rate, being occupied in all the same length of time as

the man first mentioned; at what points and at what times will he meet the first man? We will repeat in Fig. 7 the

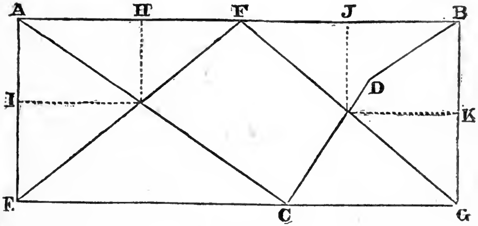

Fig. 7.

lines showing the movement of the first man, viz. A C, C D and D B. A B represents the whole time as before, and A E the distance between the two points; then will E F and F G represent the movement of the second man, and he will meet the first man on his outward trip at a distance from his starting point shown by A I, and after the time A H, and on his inward trip at a distance B K, and at the time A J.

The question below is also given in the work above referred to: A person walk-

ed out from Cambridge to a village at the rate of four miles an hour, and on reaching the railway station had to wait ten minutes for the train, which was then four and a half miles off. On arriving at his rooms, which were a mile from the Cambridge station, he found that he had been out three and a fourth hours. Find the distance of the village from Cambridge. In this case we first lay off A B, Fig. 8, equal by any scale to three and a

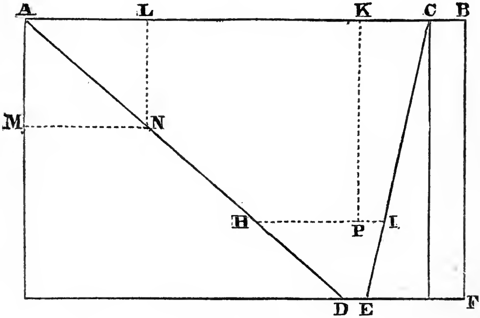

Fig. 8.

fourth hours. We next make A L equal to one hour, and A M equal to four miles, when the diagonal A N represents the

rate of four miles an hour, which we produce indefinitely. Next we go back from B to C the five minutes which it takes the man to go from the Cambridge station to his rooms, and draw the line C E, representing the rate of the railway train, and produce it indefinitely. If the man had not been obliged to wait for the train we should simply produce the two diagonals until they met, when the vertical distance of their intersection from the upper horizontal, measured on the scale of miles, would be the distance required. As, however, the man has to wait ten minutes at the station, we take the distance D E equal to that time, and find where it will just go in horizontally between the two diagonals, when the vertical distance between D E and A B will be what we require. If the whole time being the same the man had waited an hour at the station, and we wished to know the distance, we should apply the line H I, equal to one hour by the time scale, to the diagonals, and K P would give us the

distance ; or if the distance K P was given we should obtain the time H I.

Let us now pass to a somewhat different class of questions : Two men start at the same time to walk round an island ; the first man goes at the rate of five miles an hour ; the speed of the second man is such as to carry him round the island in three and a third hours, the distance being ten miles. How long after starting will the first man pass the second, and how long before he will pass him the second time ? The reader will, perhaps, at first sight not see the relation between movement on the circular path and time, as it is a little different from the relation between movement on a straight line and time. He has, however, only to observe that in traveling a circular path a man while always getting farther away from the starting point is at the same time getting nearer to it, or, in other words, he is traveling both from it and towards it at the same time. Our question above thus takes the form shown in Fig. 9, in which the movement

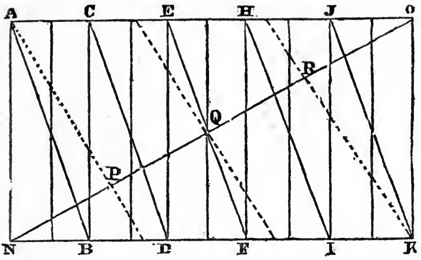

Fig. 9.

of the first man is shown by the diagonals AB, CD, EF, etc., and that of the second man by the dotted diagonals. It will be seen that having drawn AB we recommence at C; this is because in going from the point represented by the upper horizontal line to the point represented by the lower horizontal, inasmuch as the path is a circular one, we have got back again to the starting point. The first man it will be seen passes the second at five hours after starting, and again at ten hours. If, instead of both going from A towards N, one of the men goes from N towards A, we have only to start from the lower line and in-

cline the diagonal in the opposite direction, and we may vary the rates of speed, and stop the men at any points, for any length of time, without making the question any more difficult. For example, the movement of a man who should travel in the opposite direction at the rate of one mile an hour is shown by the diagonal N O, and he will meet the second of the men above referred to at P, Q and R, from which points we may draw verticals to the time line, and horizontals to the line A N, which will show us just when and where the several meetings will take place.

We find the following question in Todhunter's Algebra : A and B start together from the same point on a walking match round a circular course. After half an hour A has walked three complete circuits, and B has walked four and a half ; assuming that each walks with uniform speed find when B overtakes A. Let A B, Fig. 10, represent the length of the course, and let A C or B H represent half an hour ; then the dotted line

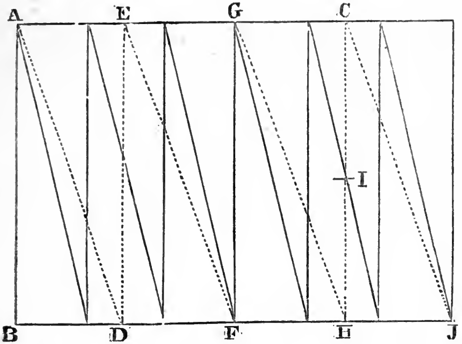

Fig. 10.

A D E F G H will show the movement of A, while the four and a half full diagonals to I will show that of B. Carrying the two sets of lines on at the same rate we find them together again at J, which by the time scale is ten minutes from the time represented by H.

Let us try some of the watch problems as given in the algebras. In Fig. 11 we have shown the movement of both the hour and minute hands for twelve hours, and we shall find that the several diagonals answer a variety of questions.

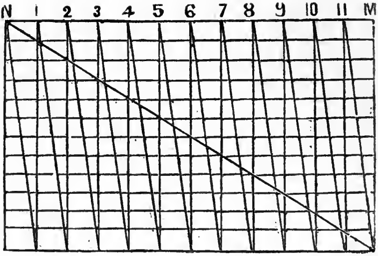

Fig. 11.

We may take the distance around the face of the watch as representing *time or distance* as we please. It represents both, and thus we lay off twelve divisions upon the upper horizontal line and also upon the left hand vertical. The long diagonal represents the course of the hour hand for twelve hours, and the short diagonals represent the twelve revolutions of the minute hand in the same time. Take now the following question: The hands of the watch are together at noon, when are they next together? We see plainly that the hands are together at noon, at a little after one o'clock, at a little more after two o'clock,

at a still longer time after three, and so on, the precise time being found by carrying the crossings of the diagonals vertically upwards to the time line. Our figure is too small to do this accurately. Let us take one hour out of the preceding diagram, and enlarge it, as in Fig. 12.

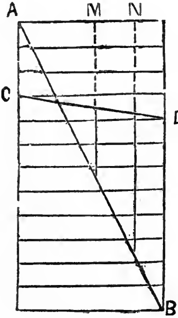

Fig. 12.

Take the following question: The hands of a watch are at right angles at three o'clock; When are they next at right angles? The hands are at right angles when they are fifteen minutes apart. The vertical divisions in Fig. 12

are each five minutes. The movement of the minute hand for an hour is shown by the diagonal A B, and that of the the hour hand by C D. Wherever we can get a vertical equal to fifteen minutes, or to A C, between the two diagonals the hands will be at right angles, and by producing this vertical to the time line, as at M, we get the required time, in the present case between thirty-two and thirty-three minutes past three o'clock. Again, let the question be to find at what time between three and four o'clock the hands will be diametrically opposite. Diametrically opposite is thirty minutes apart, and applying thirty minutes, or six of the vertical spaces, to the lines A B and C D, and producing the line upwards, we find the time line to be cut at N, or about eleven minutes before four o'clock.

It will be evident from an examina- of the preceding figures that the graphic method is not confined to questions involving *time* and *space* alone, but that it is equally applicable to questions of time

and any kind of work done, whether labor performed by men, water discharged by pipes, or the like. Take for example the following question: A can do a piece of work in five days, and B can do it in three days. In what time will both working together do it? Let A B, Fig. 13, be the time in which A can do

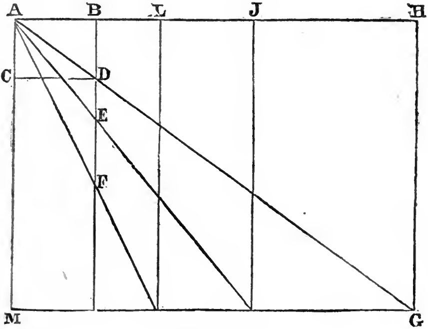

Fig. 13.

an amount of work represented by A C or B D, then will A D represent *the rate* at which he works. So, too, if B does an amount of work shown by B E, in the time A B, A E will represent his rate of

work. Make EF equal to BD. BF will show the amount of work done by both in the time AB, and AF will be the rate at which both together work. The several rates being fixed the question is at once answered. The amount of work being represented by AM, A will do it in the time represented by AH, B in a time shown by AJ, and both together in a time AL. The same diagram will of course answer other questions in regard to the two men. For example, if we know the time in which both men can do a piece of work, and also the time in which one man can do it, we find easily how long the other will be doing it.

Questions like the following are common in arithmetic and algebra: A syphon would empty a cistern in forty-eight minutes, while a cock would fill it in thirty-six minutes. When it is empty both begin to act. How soon will the cistern be filled? Of course the capacity of the cistern in this question is immaterial; assume it to be AE, Fig. 14.

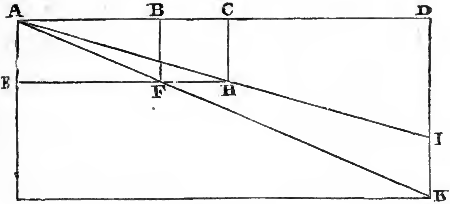

FIG. 14.

The syphon can empty it in forty-eight minutes. Lay off therefore by any scale A C equal to forty-eight. The cock can fill it in thirty-six minutes. Lay off A B equal to thirty-six. The diagonal A H will represent the rate at which the syphon empties the cistern, while the diagonal A F shows the rate at which the cock fills it. The difference between the two is, of course, the rate at which the cistern is filled. Producing therefore the diagonals until they are separated by a vertical distance equal to the assumed capacity of the cistern, A E, that is, I K, and carrying I K up to the time line at D, we have A D as the time in which the cistern will be filled by the joint action of the syphon and the cock.

Suppose that the question, instead of being as above, had been as follows: A syphon and a cock acting together will fill a cistern in 144 minutes, while the cock acting alone would fill it in thirty-six minutes? how long would it take the syphon to empty it? Lay off A D, Fig. 14, equal to 144 minutes, and A B equal to thirty-six minutes. Make A E equal to the capacity of the cistern, upon any scale. Draw E H parallel to A D, and B F perpendicular to the same. Through A and F draw a diagonal, and produce it to intersect a vertical through D at K. Make K I equal to A E, and draw I A to intersect the horizontal E H at H. From H erect a perpendicular to cut the time line at C. A C will then be the time in which the syphon alone would empty the cistern.

Let us change the question again as follows: A syphon would empty a cistern in forty minutes, while a cock would fill it in twenty-two minutes. Both commence to act, but after fifty-three minutes the cock is stopped for twenty-two

minutes, and then flows again at a rate which would fill the cistern in one hour and fifty-six minutes. When the cock recommences the syphon stops working for sixteen minutes, but after that time the cistern commences to leak at a rate which would empty it in one hour and twenty-five minutes. How long, under the new conditions, will it be from the beginning before the cistern will be half full? As the cock stops after fifty-three minutes, which time is represented upon the upper horizontal in Fig. 15 by the

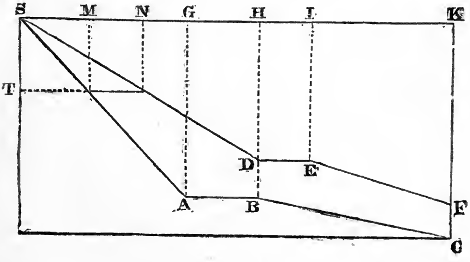

Fig. 15.

distance S G we draw A B horizontally and from B draw B C at such an angle

as to represent the new rate at which the cock supplies water. In the same manner we draw D E to show the stoppage of the syphon, and afterwards E F to represent the rate of leakage. The diagonals B C and E F must then be produced until the included vertical F C is by the scale equal to one half of the capacity of the cistern, or one half of S T. Finally we produce C F to cut the time line at K, and S K is the answer to the question.

The various questions in Alligation may be worked by the graphic method. Suppose for example that a man would mix one kind of grain worth thirty cents a bushel with another quality worth eighty cents, so as to make sixty bushels worth 50 cents a bushel ; how much of each kind must he take ? Lay off B F in Fig. 16 equal by any scale to thirty cents, B H equal to fifty cents, and B I equal to eighty cents. The several lines A F, A H and A I will represent the rates or values of the different kinds of grain. Make A J on any scale equal to

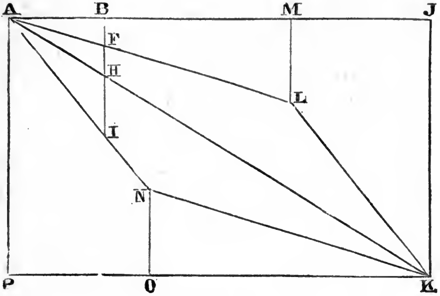

Fig. 16.

the required number of bushels in the mixture. Draw a vertical J K to meet A H, the value or rate of the mixture produced, at K. Produce A F indefinitely, and from K draw K L parallel to A I to intersect A F produced in L, and from L draw the vertical L M. A M will show the number of bushels at the price B F, and M J will give the number at the price B I. The result will of course be the same if we produce A I and draw K N parallel to A L to meet it at N, and drop the perpendicular N O on to the line P K.

Let us take a question, such as we

frequently find, like the following: A workman was hired for forty days at three shillings and four pence for every day that he worked, but with the condition that for every day he did not work he was to forfeit one shilling and four pence; he received £3 3s 4d; how many days did he work. Reduce the several amounts to the common unit of pence for convenience in plotting the work upon paper. Make A B, Fig. 17,

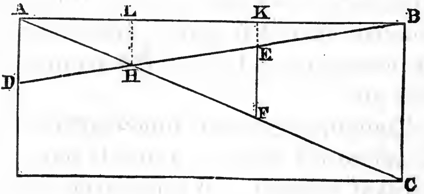

Fig. 17.

by any scale equal to forty days, and make B C equal to what he would have received had he worked all of the time. Make A D equal to what he would have lost had he worked none at all, and draw C A and D B. Find where the line E F which is equal by the scale of pence to

the whole amount he received, will just go in vertically between A C and D B and produce it upwards to K. A K upon the scale of time will then show the number of days he worked, and K B the number of days he was idle, the former being twenty-five and the latter fifteen. If we wish to know how many days he should work in order that his earnings may just balance his loss, we have only to draw from the point H, where the two diagonals cross, the vertical H L when we shall have A L as the number of days he worked and L B as the number he was idle.

Todhunter gives the following question in one of his works. A and B shoot by turns at a target. A puts seven bullets out of twelve into the bulls-eye, while B puts in nine out of twelve ; between them they put in thirty-two bullets. How many shots did each man fire ? Lay off A B, Fig. 18, equal upon any scale to thirty-two, the whole number of successful shots. Next, lay off seven of the thirty-two divisions from A to H, and

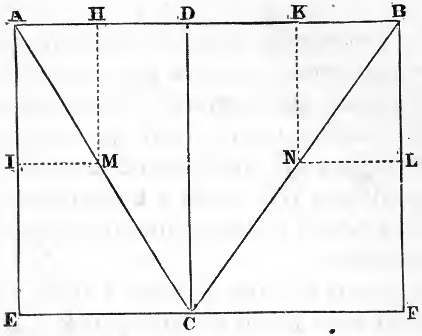

Fig. 18.

twelve of the same divisions on the vertical line from A to I, then will the diagonal A M represent A's rate of success. In the same way we lay off nine divisions from B to K and twelve divisions from B to L, and B N will represent B's rate of success. Produce A M and B N until they meet at C, and from C draw C D perpendicular to A B. C D will show the number of shots that each man fired. If A made *no* successful shots, proceeding in the same way we should lay off *no* divisions upon the line A B, and twelve upon A E, and the line representing the

rate of success would be vertical, or in other words he has no success. In such case the number of times that B would have to fire to put the thirty-two balls into the target would be found by producing B C to cut A E produced, the length of A E thus produced showing the number.

About the time that the Pacific Railroad was opened the newspapers passed around the following question: Suppose that it takes a train just one week to run the whole length of the road, and that one train leaves each end of the road each morning, how many trains will a person meet in going the length of the road, not counting the train which arrives just as he starts, nor the train that starts just as he arrives? Let the six vertical divisions in Fig. 19 represent the six

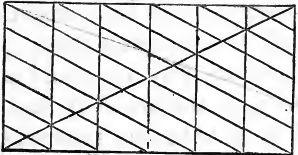

FIG. 19.

days. The diagonal from the bottom of the left hand vertical to the top of the right hand one may show the movement of the train running through in one direction, when the opposite diagonals, eleven in number, will show the number of trains which he will meet.

To what has preceded we add a few examples for practice from Todhunter's algebras. In some cases we have given the diagrams showing the form which the solution will take, while in other cases the construction of the figure is left to the reader. The ease with which many questions commonly found in the books will be answered by the graphic method will depend of course upon the more or less perfect knowledge of algebra which may be possessed.

Two plugs are opened in a cistern containing 192 gallons of water; after three hours one of the plugs becomes stopped, and the cistern is emptied by the other in eleven more hours: had six hours elapsed before the stoppage it would have required only six hours more

to have emptied the cistern. How many gallons will each hole discharge in an hour, supposing the discharge uniform. In Fig. 20 A B represents three hours,

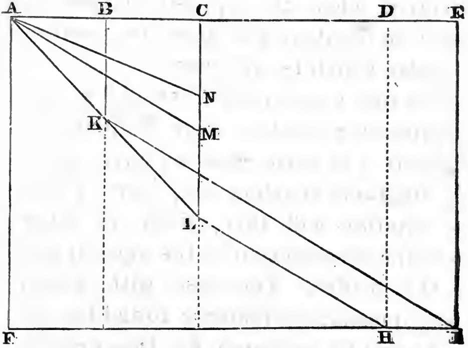

FIG. 20.

B C three hours, C D six hours, and D E two hours. A K shows the discharge by the two plugs for three hours, and K I the discharge by one plug for the eleven hours additional. The inclination of the lines must be such that when A, K and L are in a straight line, L H and K I shall be parallel. The inclination A L will show the rate of discharge of both

plugs, and K I or A M will show the rate of one, while the difference between these two or A N will show the rate of the other.

The road from a place A to a place B first ascends for five miles, is then level for four miles, and afterwards descends for six miles the rest of the distance. A man walks from A to B in three hours and fifty-two minutes; the next day he walks back to A in four hours, and he then walks half way back to B and back again to A in three hours and fifty-five minutes. Find his rates of walking up hill, on level ground and down hill.

A and B are two towns situated 24 miles apart upon the same bank of a river. A man goes from A to B in seven hours by rowing the first half of the distance, and walking the second half. In returning he walks the first half at three-fourths of his former rate, but the stream being with him he rows at double his rate in going, and he accomplishes the whole of the distance in six hours. Find his rates of walking and rowing.

A and B set out to walk together in in the same direction round a field, which is a mile in circumference, A walking faster than B. Twelve minutes after A has passed B for the third time, A turns and walks in the opposite direction until six minutes after he has met him for the third time, when he returns to his original direction and overtakes B four times more. The whole time since they started is three hours, and A has walked eight miles more than B. A and B diminish their rates of walking by one mile an hour, at the end of one and two hours respectively. Determine the velocities with which they began to walk.

A vessel can be filled with water by two pipes; by one of the pipes alone the vessel can be filled two hours sooner than by the other; also the vessel can be filled by both pipes together in $1\frac{7}{8}$ hours. Find the time which each pipe alone would take to fill the vessel. The diagram given upon a preceding page, Fig. 13, is the same as that required for the above question, by which the answer will be seen to be three and five hours.

A offers to run three times round a course while B runs twice round, but A only gets 150 yards of his third round finished when B wins. A then offers to run four times round for B's thrice, and now runs four yards in the time he formerly ran three yards. B also quickens his rate so that he runs 9 yards in the time he formerly ran 8 yards, but in the second round falls off to his original pace in the first race, and in the third round goes only 9 yards for 10 he went in the first race, and accordingly this time A wins by 180 yards. Determine the length of the course.

A boat's crew row $3\frac{1}{2}$ miles down a river and back again in an hour and 40 minutes. Supposing the river to have a current of 2 miles an hour, find the rate at which the crew would row in still water.

A and B start together from the foot of a mountain to go to the summit. A would reach the summit half an hour before B, but, missing his way, goes a mile and back again needlessly, during which

he walks at twice his former pace, and reaches the top six minutes before B. C starts twenty minutes after A and B, and walking at the rate of two and one-seventh miles per hour, arrives at the summit ten minutes after B. Find the rates of walking of A and B, and the distance from the foot to the summit of the mountain.

A and B are set to a piece of work which they can finish in thirty days working together, and for which they are to receive £7,10s. When the work is half finished, A stops working for eight days and B for four days, in consequence of which the work occupies five and a half days more than it would otherwise have done. How much ought A and B respectively to receive?

A body of troops retreating before the enemy, from which it is at a certain time 26 miles distant, marches 18 miles a day. The enemy pursues it at the rate of 23 miles a day, but is first a day later in starting, then, after two days' march, is forced to halt for one day to repair a

bridge, and this they have to do again after two days more marching. After how many days from the beginning of the retreat will the retreating force be overtaken? A B, in Fig. 21, represents

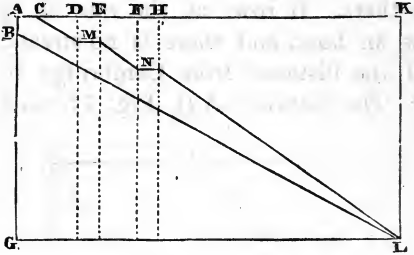

Fig. 21.

26 miles, A C one day, C D two days, D E one day, E F two days, and F H one day. The inclination of the line B L represents the rate at which the retreating troops march, and the inclination of C M or M N or N L shows the rate of the pursuers. The horizontals M and N are the two halts of a day each. The two diagonals are to be produced until they cut, as at L, when A K will give us

the time, and A G or K L the distance required.

A rows at the rate of $8\frac{1}{3}$ miles an hour. He leaves Cambridge at the same time that B leaves Ely, and is back in Cambridge 2 hours and 20 minutes after B gets there. B rows at the rate of $7\frac{1}{2}$ miles an hour, and there is no stream. Find the distance from Cambridge to Ely. The distance A B, Fig. 22, must

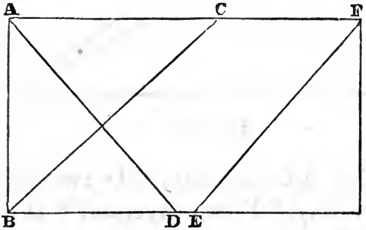

FIG. 22.

be such that when A D represents $8\frac{1}{3}$ miles an hour, D E 12 minutes, E F $8\frac{1}{3}$ miles an hour, and B C $7\frac{1}{2}$ miles an hour, C F shall be equal to 2 hours and 20 minutes.

Two workmen A and B are employed

by the day at different rates. A at the end of a certain number of days received £4 16s., but B, who was absent six of the days, received only £2 14s. If B had worked the whole time, and A had been absent the six days, they would both have received the same. Find the number of days, and what each was paid per day. A C, in Fig. 23, shows the

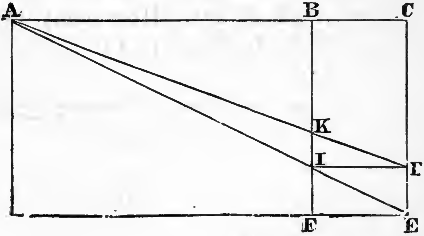

FIG. 23.

whole time, B C being six days. C E is equal to £4 16s., and B K to £2 14s. A B must be such that D I being drawn parallel to A C the lines drawn through E and I and through D and K shall meet upon the line A B.

A waterman rows thirty miles and

back in twelve hours, and he finds that he can row five miles with the stream in the same time as three against it. Find the times of rowing up and down.

A person hired a laborer to do a certain work on the agreement that for every day he worked he should receive 2s., but that for every day he was absent he should lose 9d.; he worked twice as many days as he was absent, and on the whole received £1 19s. How many days did he work? In Fig. 24, A C is to be

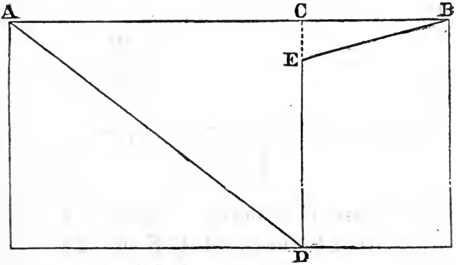

Fig. 24.

twice as great as C B, A D is to represent the man's rate of receipt while he worked, and B E his rate of loss while idle.

E D is to be equal by the scale to £1 19s.

A man and a boy being paid for certain days' work, the man received 27 shillings, and the boy, who had been absent three days out of the time, received twelve shillings. Had the man instead of the boy been absent three days they would have received the same amount. Find the wages of each per day. In Fig. 25, A E represents the whole time,

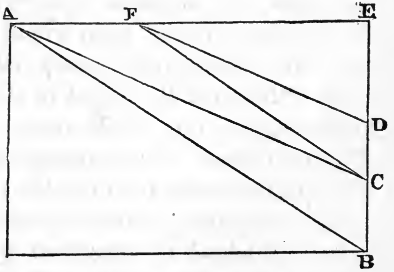

Fig. 25.

A B the man's rate of work, E B what he received, A F three days, F D the boy's rate of work, and E D what the boy received; A C parallel to F D, shows

the boy's work for the whole time, and F C, parallel to A B, the man's work omitting three days. The inclinations of the lines must be such that F C and A C parallel, respectively, to A B and F D shall meet on E B.

A railway train after traveling for one hour meets with an accident which delays it one hour, after which it proceeds at three-fifths of its former rate, and arrives at the terminus three hours behind time ; had the accident occurred fifty miles further on, the train would have arrived one hour and twenty minutes sooner. Required the length of the line, and the original rate of the train.

The fore wheel of a carriage makes six revolutions more than the hind wheel in going 120 yards; if the circumference of the fore wheel be increased by one-fourth of its present size, and the circumference of the hind wheel by one-fifth of its present size, the six will be changed to four. Required the circumference of each wheel.

A and B can do a piece of work to-

gether in 48 days ; A and C can do it in 30 days ; and B and C working together can do it in $26\frac{2}{3}$ days. Find the time in which each could do the work alone.

A man starts from the foot of a mountain to walk to its summit. His rate of walking during the second half of the distance is half a mile per hour less than his rate during the first half, and he reaches the summit in $5\frac{1}{2}$ hours. He descends in $3\frac{3}{4}$ hours, walking at a uniform rate which is one mile an hour more than his rate during the first half of the ascent. Find the distance to the summit, and his rates of walking. In Fig. 26, A B represents $5\frac{1}{2}$ hours, B C $3\frac{3}{4}$ hours, and A D the distance required. A H shows his movement during the first half of the ascent, H E that during the second half, and E C his descent.

A sets off from London to York, and B at the same time from York to London, and they travel uniformly. A reaches York 16 hours and B reaches London 36 hours after they have met on the road. Find in what time each has

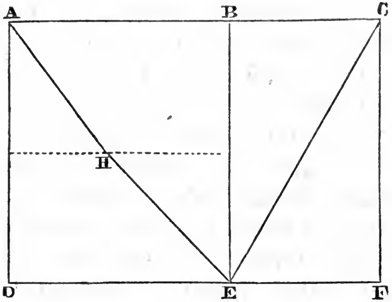

Fig. 26.

performed the journey. In Fig. 27, AF

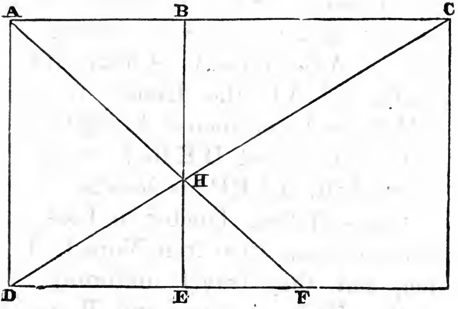

Fig. 27.

represents A's movement, and DC that

of B; E F is sixteen and B C 36 hours. The intersection of F A with A C and of C D with the lower horizontal must fall on the same vertical, A D.

Two trains of cars, 92 feet and 84 feet long respectively, are moving with uniform velocities on parallel tracks. When they go in opposite directions they pass each other in one second and a half; but when they go in the same direction the faster train passes the other in six seconds. Find the rate at which each train moves.

Two travelers, A and B, start from two places, P and Q, at the same time. A starts from P with the design to pass through Q, and B starts from Q and travels in the same direction as A. When A overtook B it was found that they had together traveled thirty miles, that A had passed through Q four hours before. and that B at his rate of traveling was nine hours' journey distant from P. Find the distance between P and Q. In Fig. 28, P R is nine hours, T S is four hours, and P V plus Q V is thirty miles.

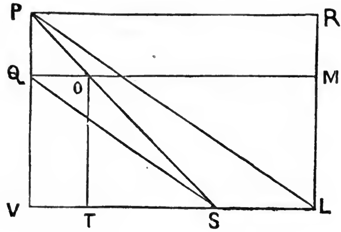

Fig. 28.

P Q, the distance required, must be such that Q S being drawn parallel to P L, S P shall cut Q M in a point, O, which shall be four hours back of S.

We will conclude by an application of the graphic method to a question of great practical importance, viz. the adjustment of the running times of railway trains, which, as before stated, has been for a long time employed by railway managers, and which first suggested to the writer the solutions given in the preceding pages.

Let the heavy vertical lines, in Fig 29,* represent the successive hours of the day, and the intermediate finer lines the

* Frontispiece.

quarter hours. The horizontal lines represent the several stations along the road, the vertical distances between them being laid off by scale according to the actual distances in miles. Suppose that we wish to start a train at six o'clock A. M., from the station represented by the line A A, so that it shall arrive at the station shown by the line J J at three o'clock P. M. stopping fifteen minutes at each way station. The number of way stations being eight, the whole time consumed by stops will be 120 minutes, or two hours. From 3 P. M. upon the lower horizontal line we go back two hours, or to 1 P. M. and from 6 A. M. upon the upper horizontal we draw a line which produced would strike 1 P. M. upon the lower line. This diagonal reaches the line B B at 7:23 A. M. As we stop at the station 15 minutes, we pass along *on the line* B B a distance equal to fifteen minutes on the time scale, and from the point thus reached we start again parallel to the first diagonal, ariving at station C at 8:20 A.

M. Proceeding in the same way we arrive at station J at 3 P. M., as desired. The inclination of the diagonal shows the speed.

If we would start a train from station A at 8:30 A. M. to arrive at J at 11:15, making no stops, it would pass the train above described at station D, and will run the whole distance in two hours and 45 minutes. Trains running in the opposite direction are shown on the diagram by diagonals ascending from left to right. Thus a train leaving station J at 6 A. M., to arrive at station A at noon making no stops, will run as by the broken diagonal from 6 A.M., on the lower line to 12 on the upper one, passing the 6 A. M and the 8:30 A. M. trains, running in the opposite direction, at station D. It will be observed that the line from 6 to 12 changes its rate of inclination at the horizontal D, by which we understand that the train changes its rate of speed at that station, running faster from D to A than from J to D.

If it is desired to work a construction

train between the stations E and D from 6 A. M. to 6 P. M., the movement of such a train is shown by the short diagonals between the horizontals D and E, and its time card would be as follows: Leave E at 6 A. M., and arrive at D at 7. Leave D at 7:15 and arrive at E at 8:15. Leave E at 8:30 and arrive at D at 9:30, crossing the 6 A. M. and the 8:30 A. M. trains from A to J, and being passed by the 6 A. M. train from J to A. Leave D at 10 and arrive at E at 11. Leave E at 11:15 and arrive at D at 12:-15, and wait to be passed by the 9 A. M. train from J to A. Leave D at 12:45 P. M. and arive at E at 1:30 P. M., leave E at 1:45 and arrive at D at 2:45, and pass noon train from station A, and 11:15 A. M. train from station J. Leave D at 3:15 and arrive at E at 4 P. M. Leave E at 4:15 and arrive at D at 5 P. M. Leave D at 5:15 and arrive at E at 6 P. M.

If a train leaves A at noon and runs towards J, leaving C at 2:05 and reaching E at 3:20, and another train leaves J at 11:15 A. M., and G at 1 P. M., run-

ning to A as by the diagonal, without stopping, the trains will pass at 3 P. M. at a point between D and E, the exact position of which may be found by the scale of miles according to which the length of the road or the distance A J is plotted, at which place a side track must be provided.

In practice the diagram is accurately drawn to a large scale, and the several trains are represented by differently colored elastic lines fastened by pins so that they may be moved from hour to hour through the day and night as the various occurences upon the road may demand, some trains being hastened others retarded, extras put in and all provisions made for securing regularity in the movement and freedom from disaster. The grades and curves may if desirable be shown upon the vertical line A J, by which those parts of the road may at once be seen where from increased resistance a lower speed will need to be adopted. Upon a double track road a chart

may be prepared for each track, and diagonals in one direction only will appear upon each diagram.

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